Not just detection:
Moving towards *attribution* of change agent using Landsat time series information
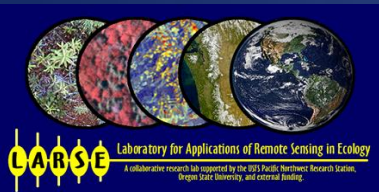
Robert E. Kennedy[1], Zhiqiang Yang[1], Justin Braaten[1]
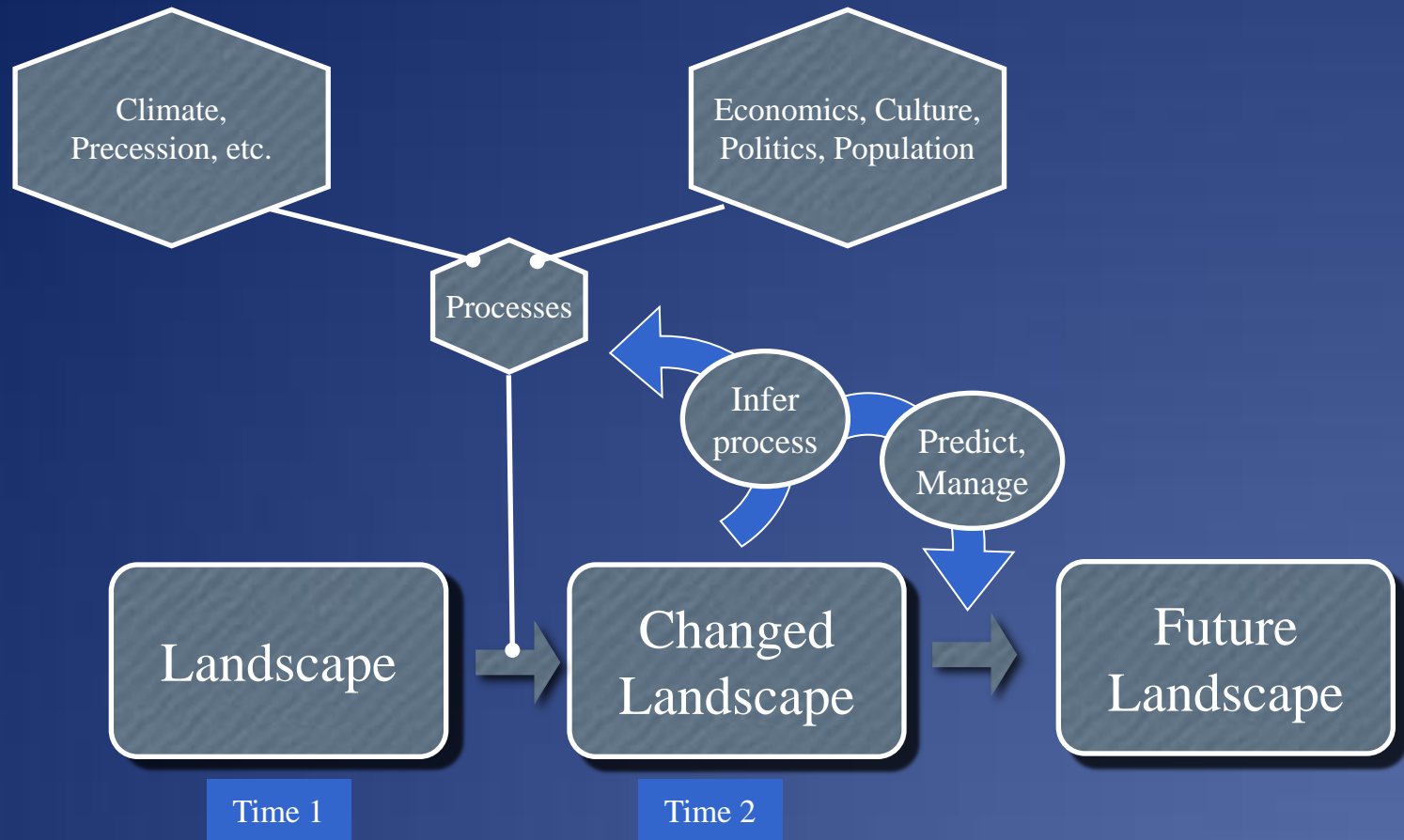
Warren B. Cohen[2]

[1] *Department of Forest Ecosystems and Society, Oregon State University*
[2] *USDA Forest Service Pacific Northwest Research Station*

Landsat Science Team Meeting, Phoenix, March 2011

Laboratory for Applications of Remote Sensing in Ecology
A collaborative research lab supported by the USFS Pacific Northwest Research Station, Oregon State University, and external funding.

OSU Oregon State UNIVERSITY

1

Climate, Precession, etc.

Economics, Culture, Politics, Population

Processes

Infer process

Predict, Manage

Landscape

Changed Landscape

Future Landscape

Time 1

Time 2

To infer and predict, we need to know what caused the change

2

Better Detection = Tougher Attribution

Luxury Changes

- Spectrally distinct
- Abrupt in time
- Large in area
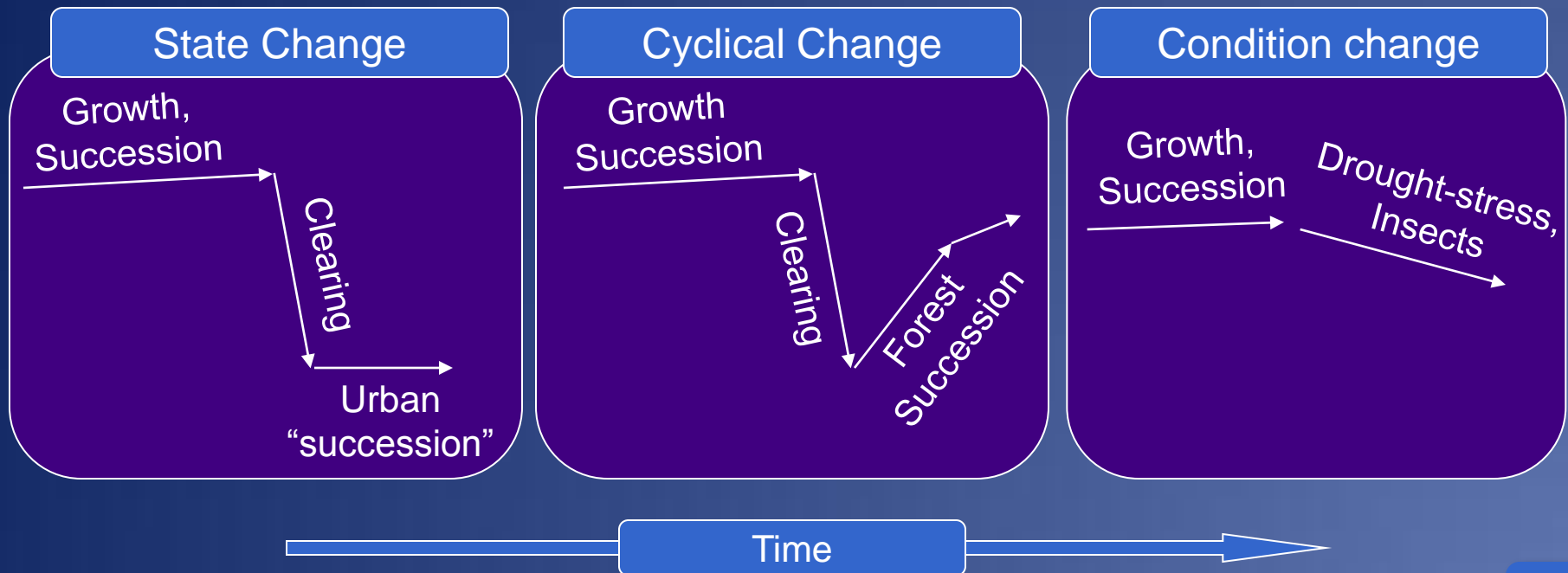- Unambiguously validated
- Single-agent

Challenging Changes

- Spectrally ambiguous
- Long- and short-duration
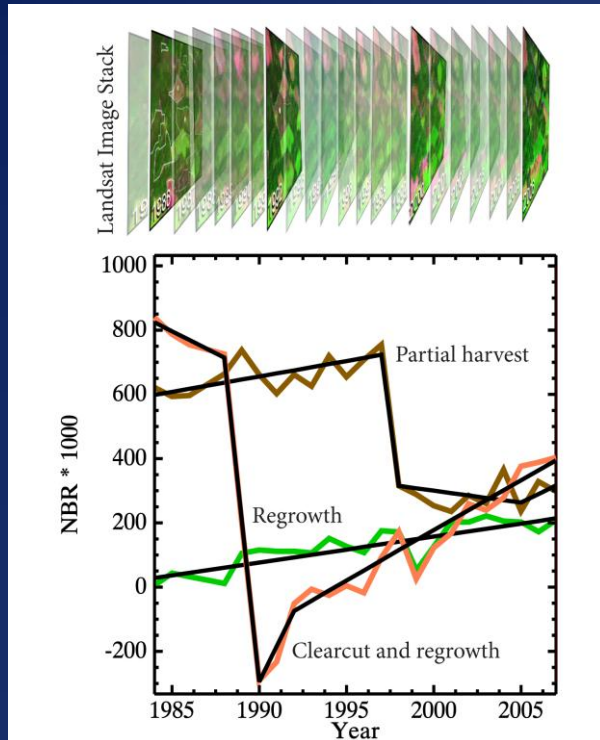- Small area
- Hard to validate
- Multi-agent

Are there organizing principles?

- Change occurs *all the time*
  - Internal and external processes
  - Variable velocities and magnitudes: Vectors
- What matters is when the *processes change*
  - Result: Shift in direction of change vectors

| State Change	Cyclical Change	Condition change
Growth, Succession — Clearing — Urban "succession"	Growth Succession — Clearing — Forest Succession	Growth, Succession — Drought-stress, Insects

Time →

- Spectral trajectories can act as proxies for that change
- LandTrendr* strategy
  - Simplify temporal trajectory into periods of consistent process: SEGMENTS
  - Separated by VERTICES

* "Landsat based detection of trends in disturbance and recovery"; See Kennedy et al. 2010 RSE 2897-2910

Landtrendr.forestry.oregonstate.edu

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Distribution of pixelwise disturbance magnitudes by ownership
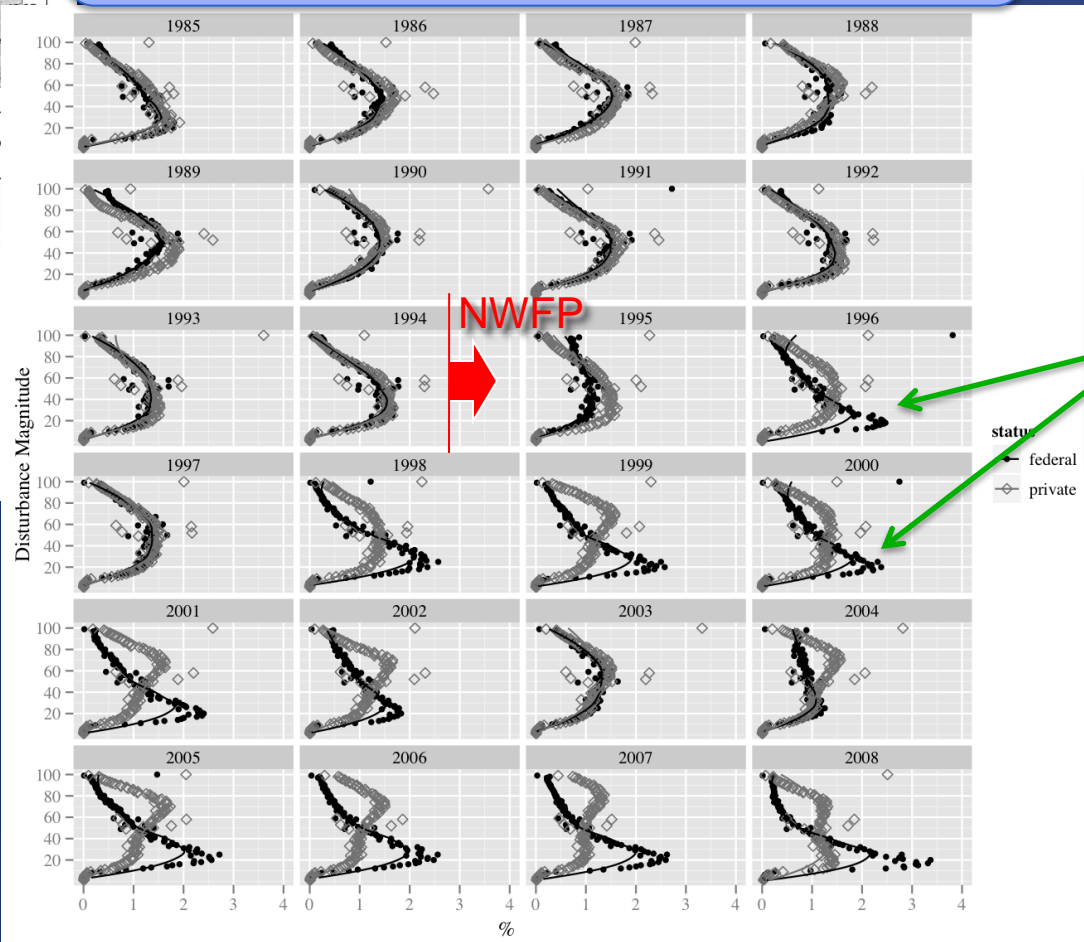
Disturbance magnitude dropped on federal forests under Northwest Forest Plan (1994)

Principle Two: Attribution must be at patch scale

- The vocabulary of attribution is inherently patch-based
  - "Development", "Thinning", etc.
- At a pixel scale, the signal is really about biophysical properties
  - Processes of vegetation loss or gain
- Similar biophysical signals have different meanings in a patch context
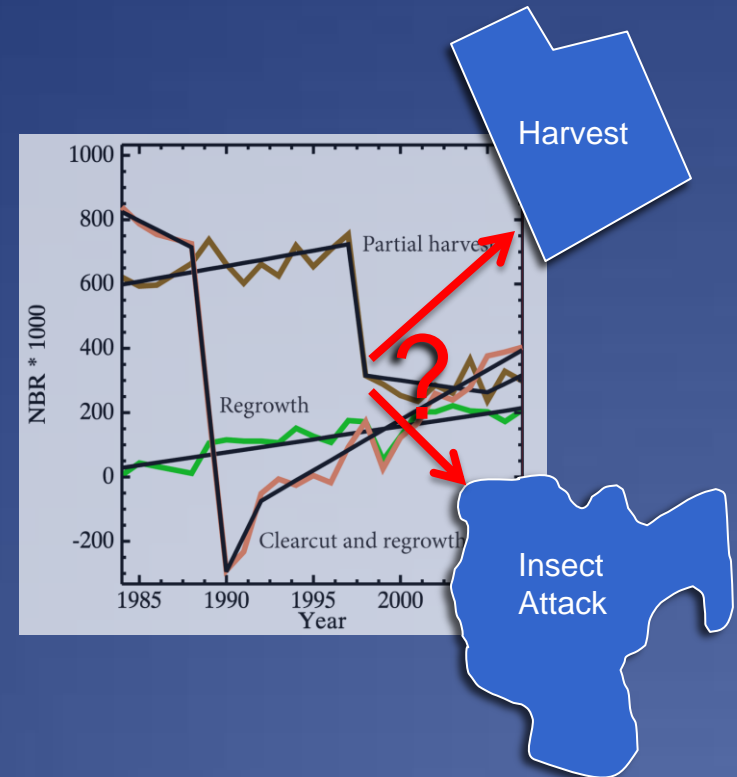
But what makes a patch?

Is it adjacency in the same year?

Maybe, but longer-duration processes, temporal overlap should be considered
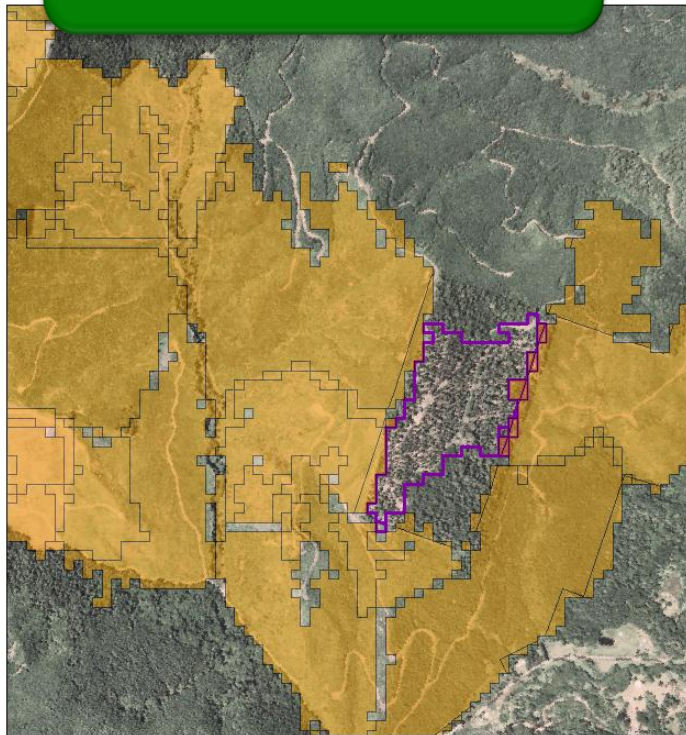
Legend

Forest disturbance Classes *Forest Disturbance Classes 1984 - 2002, 2006-2008*
Forest Disturbance Classes 2003-2005
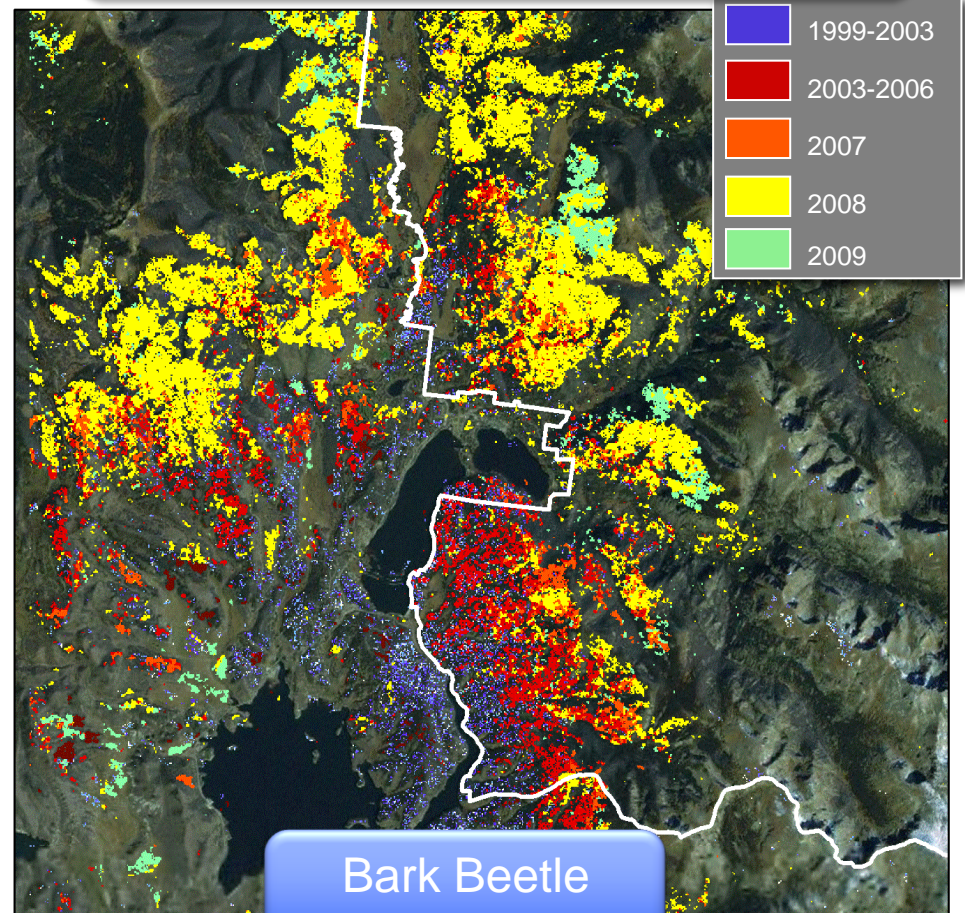**Disturbance Classes**
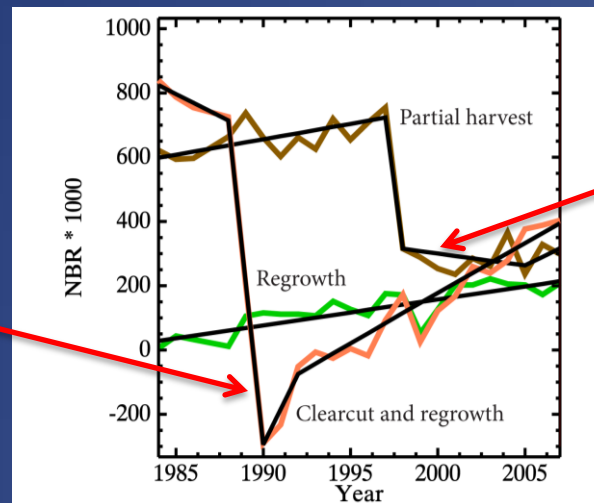Harvest Hi...
Harvest Lo...

Partial Harvest

	1999-2003
	2003-2006
	2007
	2008
	2009

Bark Beetle RMNP

- Vocabulary of attribution is implicitly temporal
  - "Clearcutting" implies forest management that may return to forest, but "Development" implies a state change
- Attribution of a change in process can be aided by knowing the processes occurring before and after
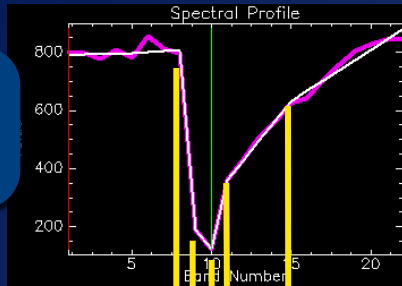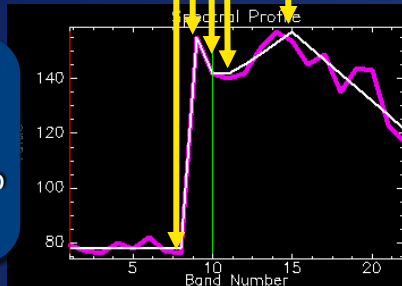

High-magnitude disturbance followed by regrowth

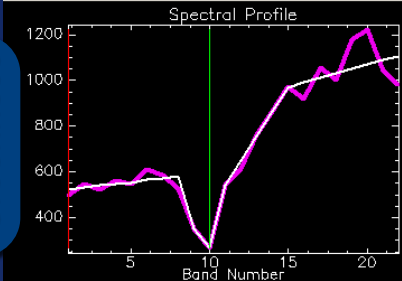Low-magnitude disturbance followed by continued decline

Spectral signals of change

NBR

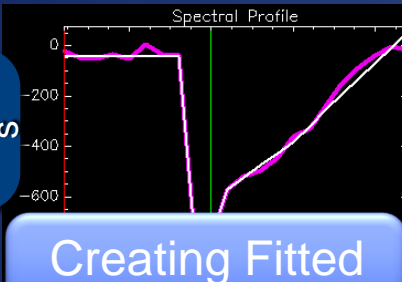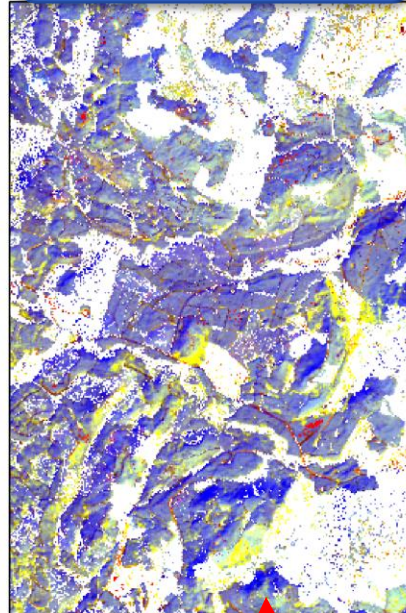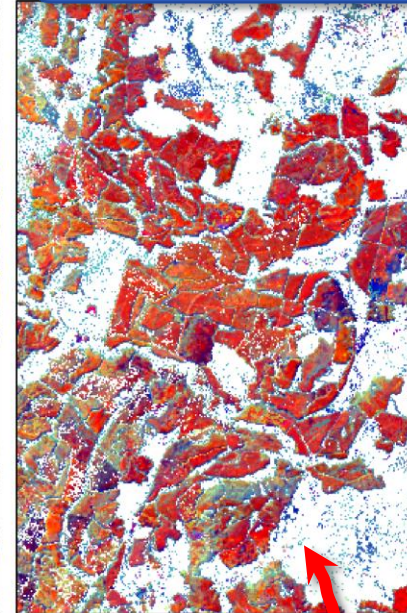Brightness

Greenness

Wetness

Creating Fitted Multispectral

Pre-disturbance BGW*

Disturbance BGW

Regrowth BGW

0   1,250   2,500   5,000 Meters
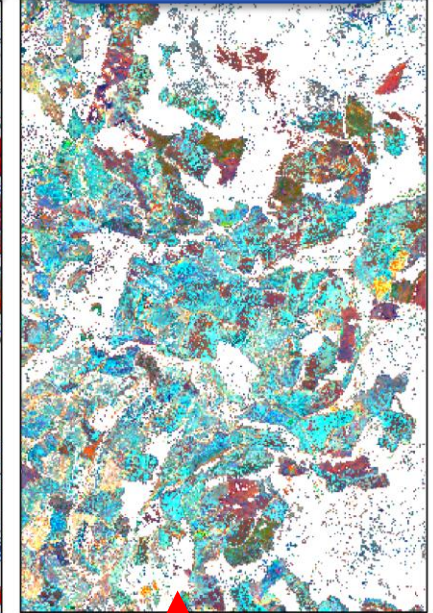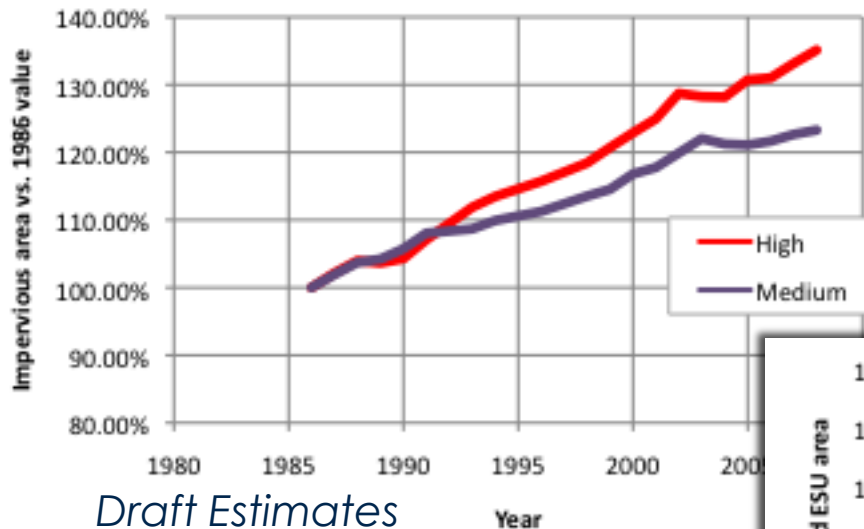
*BGW: Tasseled-cap Brightness, Greenness, Wetness

1991

2001

Difference
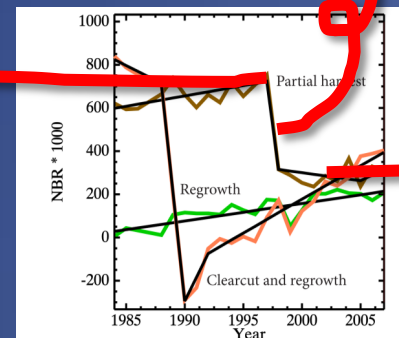
Relative increase in impervious cover is high, but absolute proportion low

Draft Estimates

Note: These estimates only for lowlands (< 150m elevation)

Classifier based on a sing... other years to ch...

Draft Estimates

11
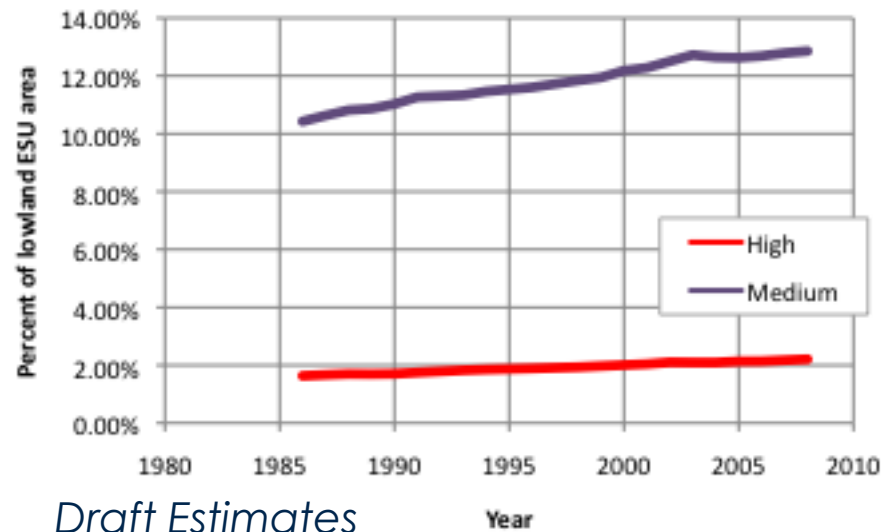
Example: Yearly NLCD

Trends in land cover classes in the Puget Sound (draft estimates)

Legend:
- Cultivated crop
- Pasture/Hay
- Developed high < 150
- Developed medium < 150
- Developed low < 150
- Evergreen forest
- Mixed forest
- Deciduous forest
- Shrub/scrub
- Grass
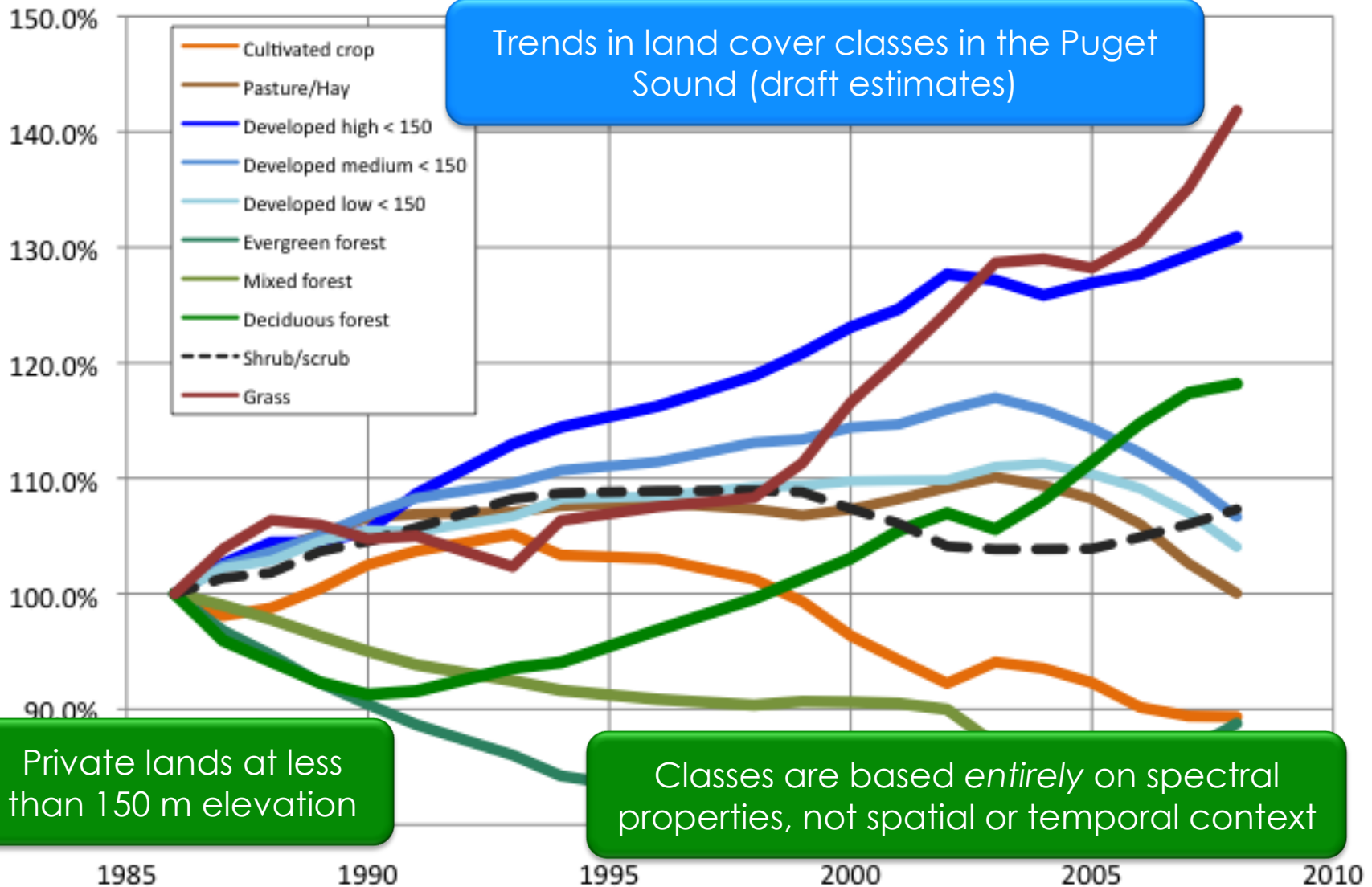
Private lands at less than 150 m elevation

Classes are based *entirely* on spectral properties, not spatial or temporal context

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Principle Four: Humans need to be involved

- Final goal may be automation, but definitions of change need to first be called by humans
  - Spatial context
  - Labeling
- Use TimeSync tool along with Google Earth

July 9, 1990

June 1, 2010

TimeSync

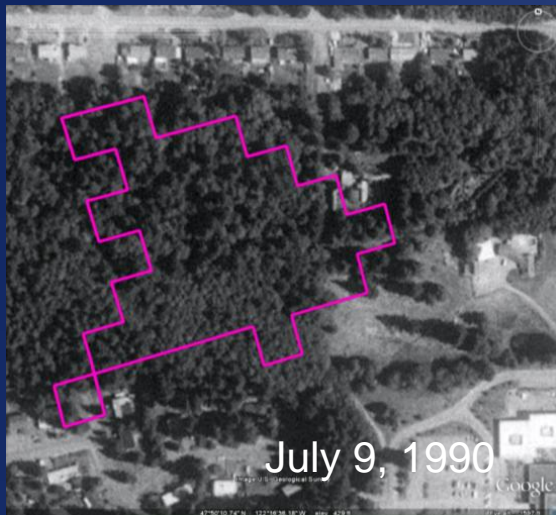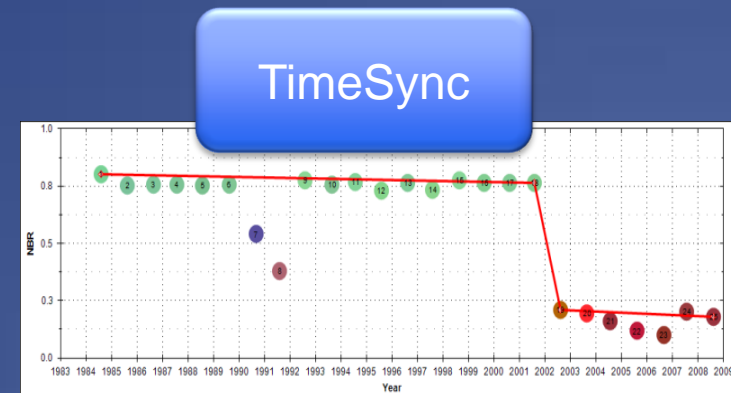"Development", not "Clearcutting"

13

- Goal of attribution: Maximize change information and leverage human interpretation for large-area attribution modeling

Pixel

Patch

Map: Pixel change

Principle 2

Sync interpretation

Detection accuracy

Filter to minimum mapping unit, make polygons

Principles 1 & 3

Map: Polygons change

DEMs, LT

Principle

Improved set

Label accuracy

Human: Assign Label

Random Assign Label

Iterative modeling cycle

an: Label

Training set

Labeled polygons

14
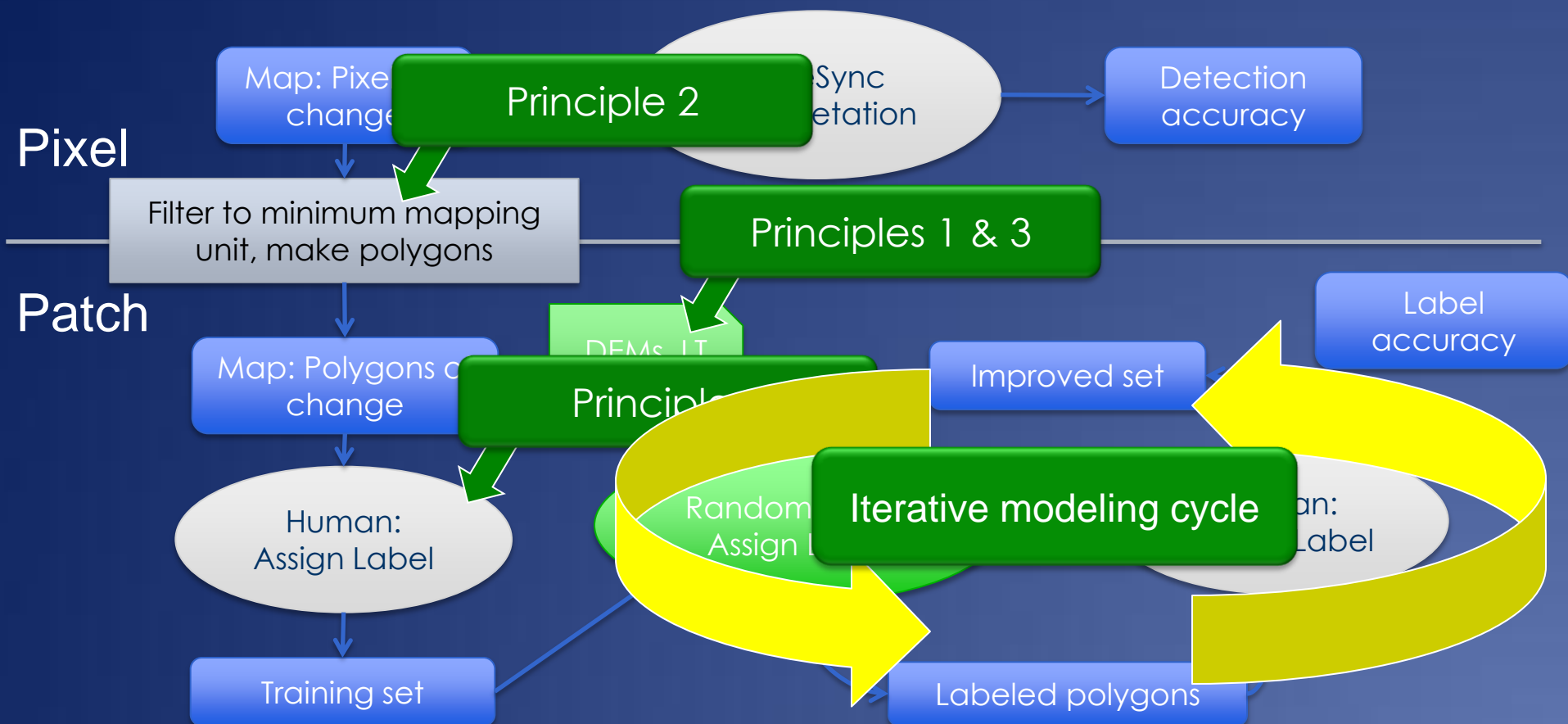
- Attribution is playing a role in several new & upcoming projects
  - Carbon cycle science project
  - National park projects
  - Habitat monitoring for salmonids

- New carbon cycle science project aims to link change, FIA plots, and change attribution to better understand drivers of carbon change
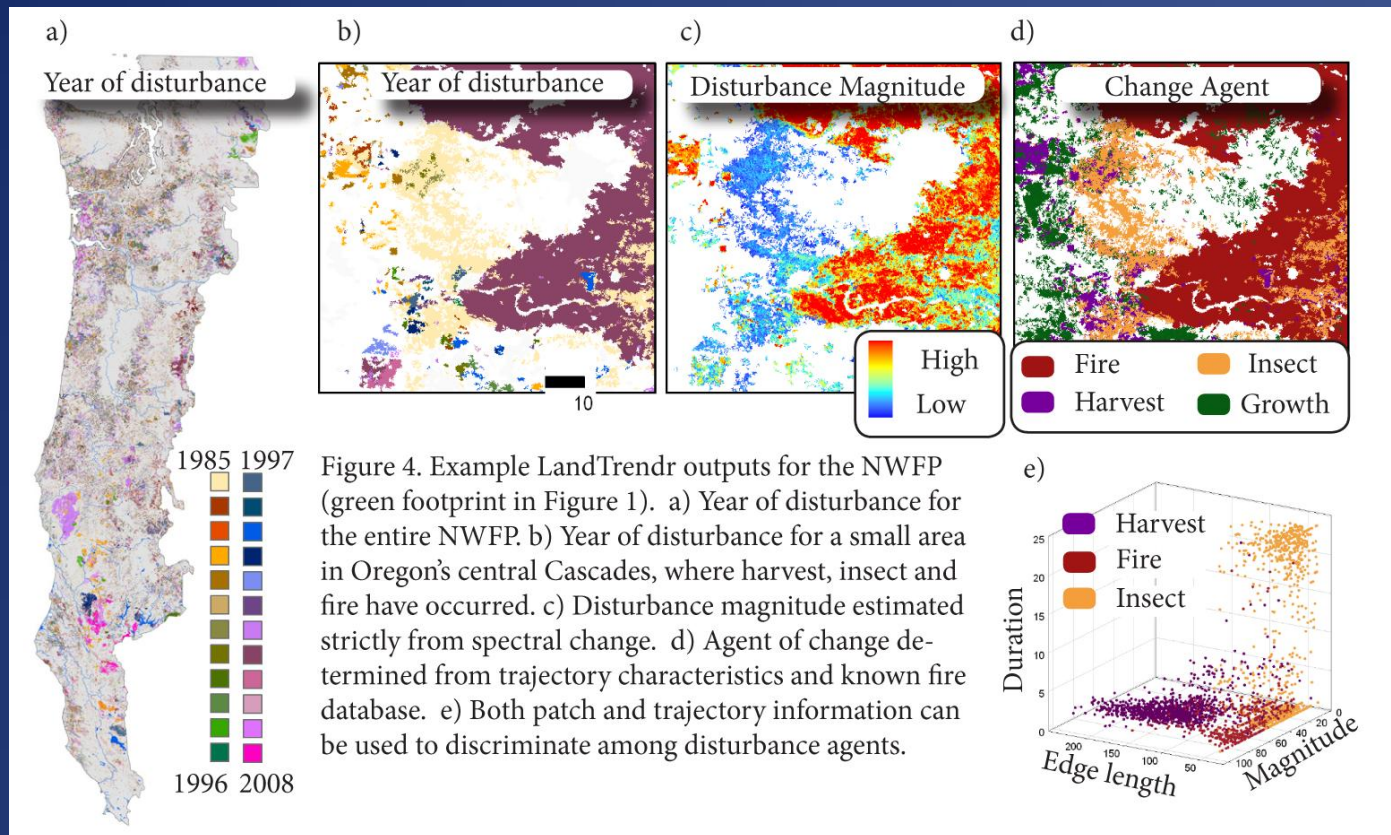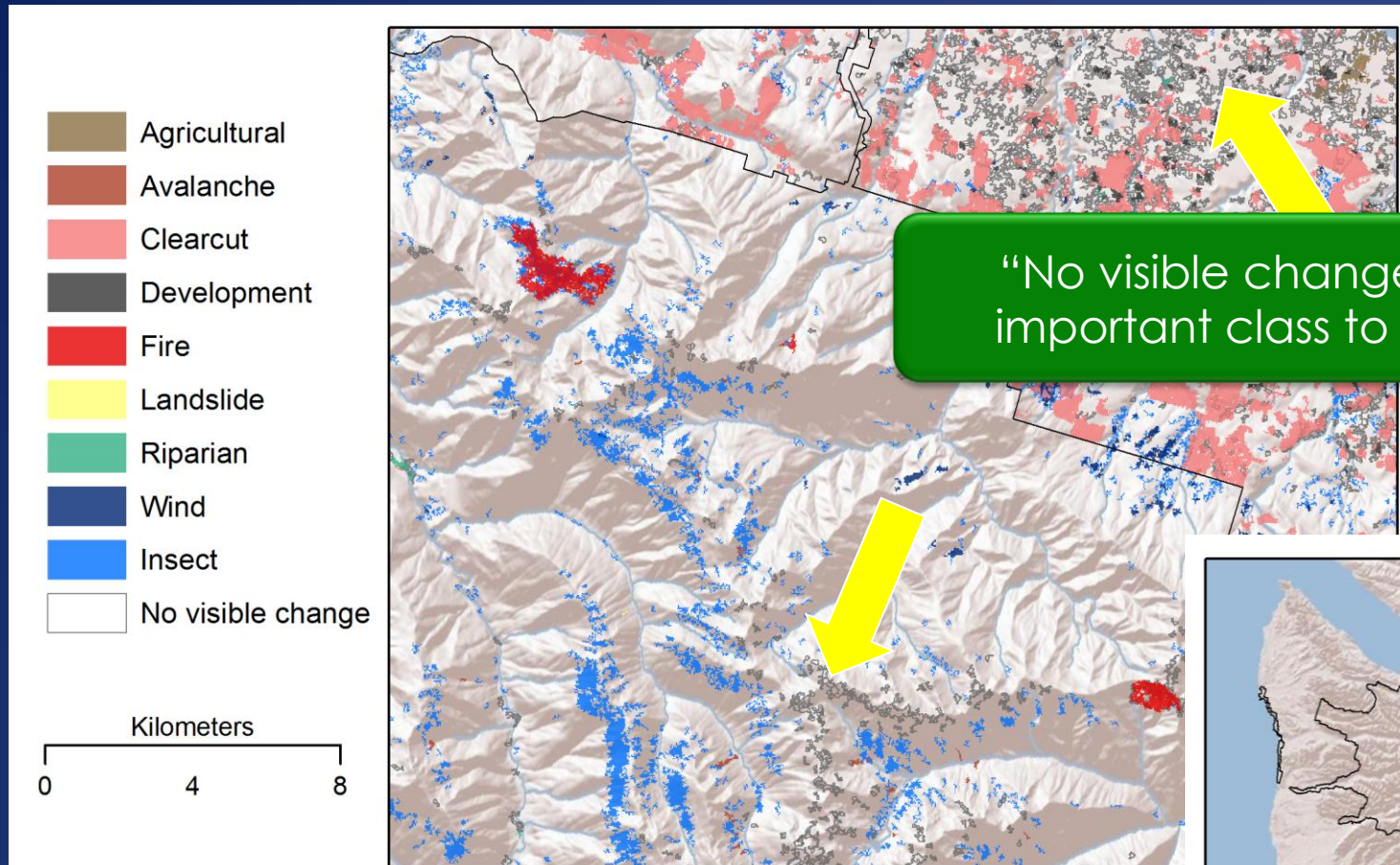

Figure 4. Example LandTrendr outputs for the NWFP (green footprint in Figure 1). a) Year of disturbance for the entire NWFP. b) Year of disturbance for a small area in Oregon's central Cascades, where harvest, insect and fire have occurred. c) Disturbance magnitude estimated strictly from spectral change. d) Agent of change determined from trajectory characteristics and known fire database. e) Both patch and trajectory information can be used to discriminate among disturbance agents.

Agricultural
Avalanche
Clearcut
Development
Fire
Landslide
Riparian
Wind
Insect
No visible change

Kilometers
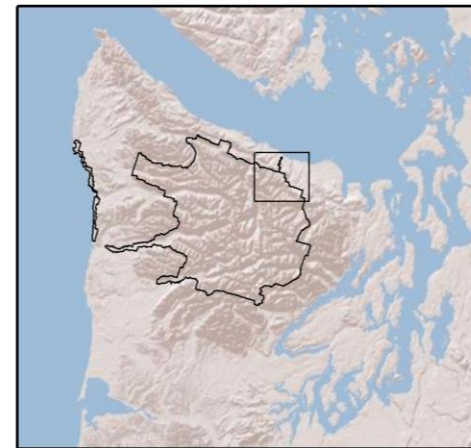0   4   8

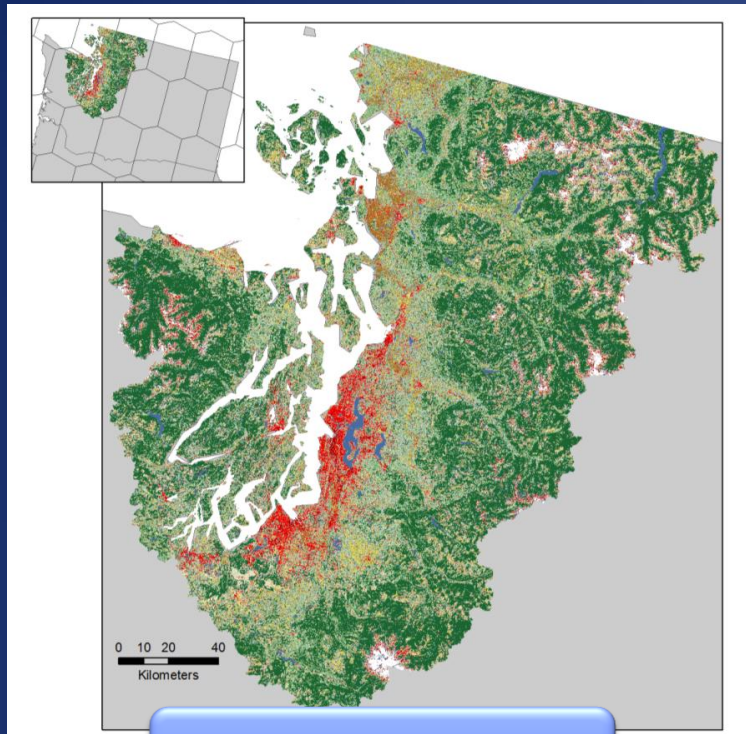"No visible change" is an important class to model!
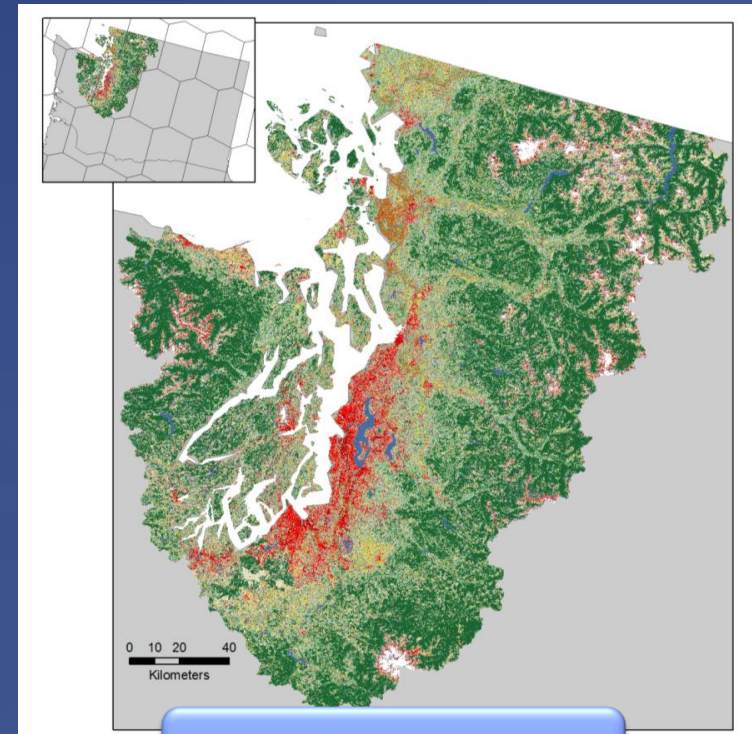
Expert human interpretation from local park staff is critical

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- Prior work focuses on natural vegetation, primarily in forests
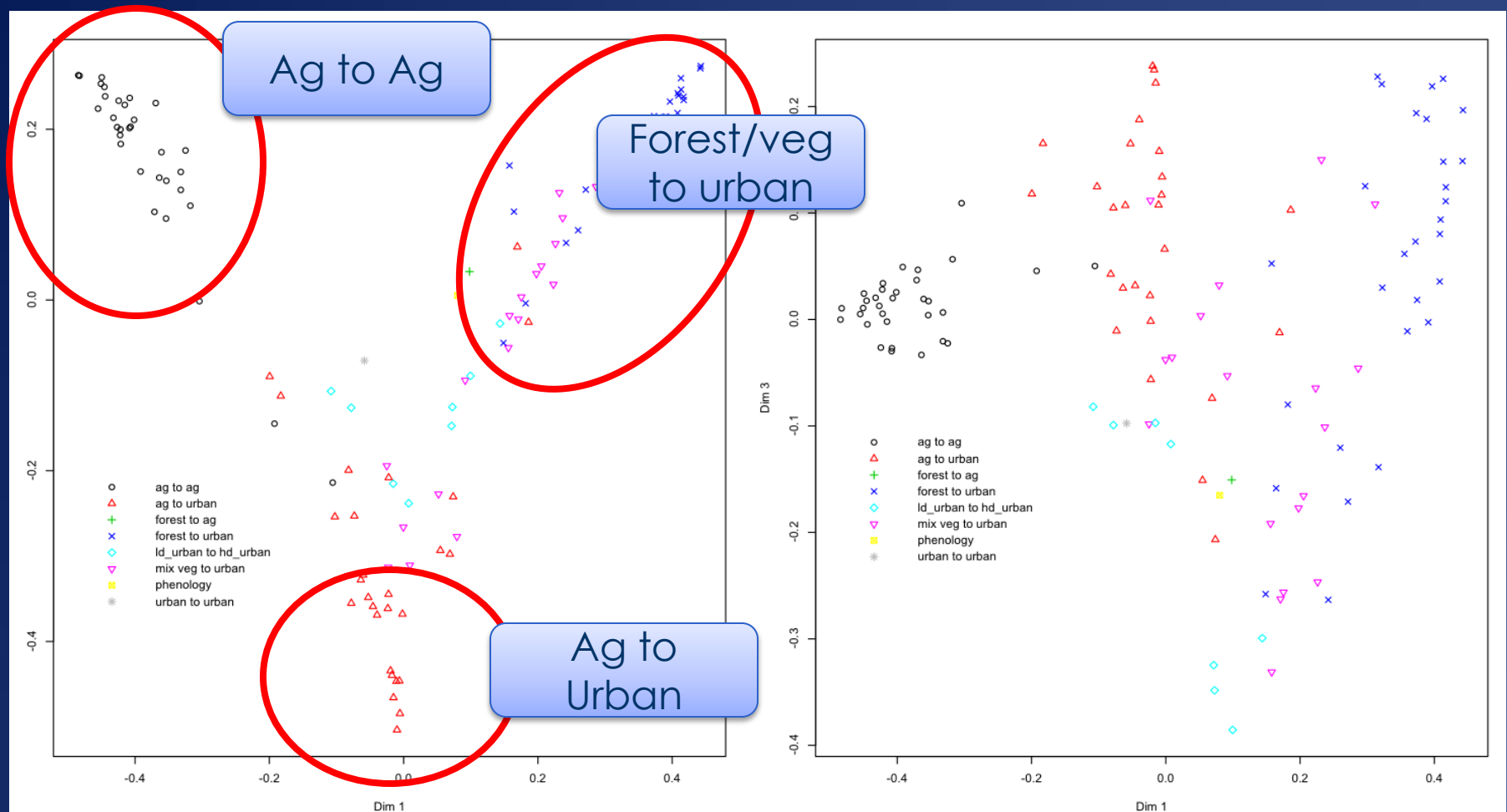- Monitoring for salmonids requires us to cover entire watersheds

1986 NLCD[LT]

2005 NLCD[LT]

18

Attribution model outside of forest is promising

Ag to Ag

Forest/veg to urban

Ag to Urban

Initial errors already good

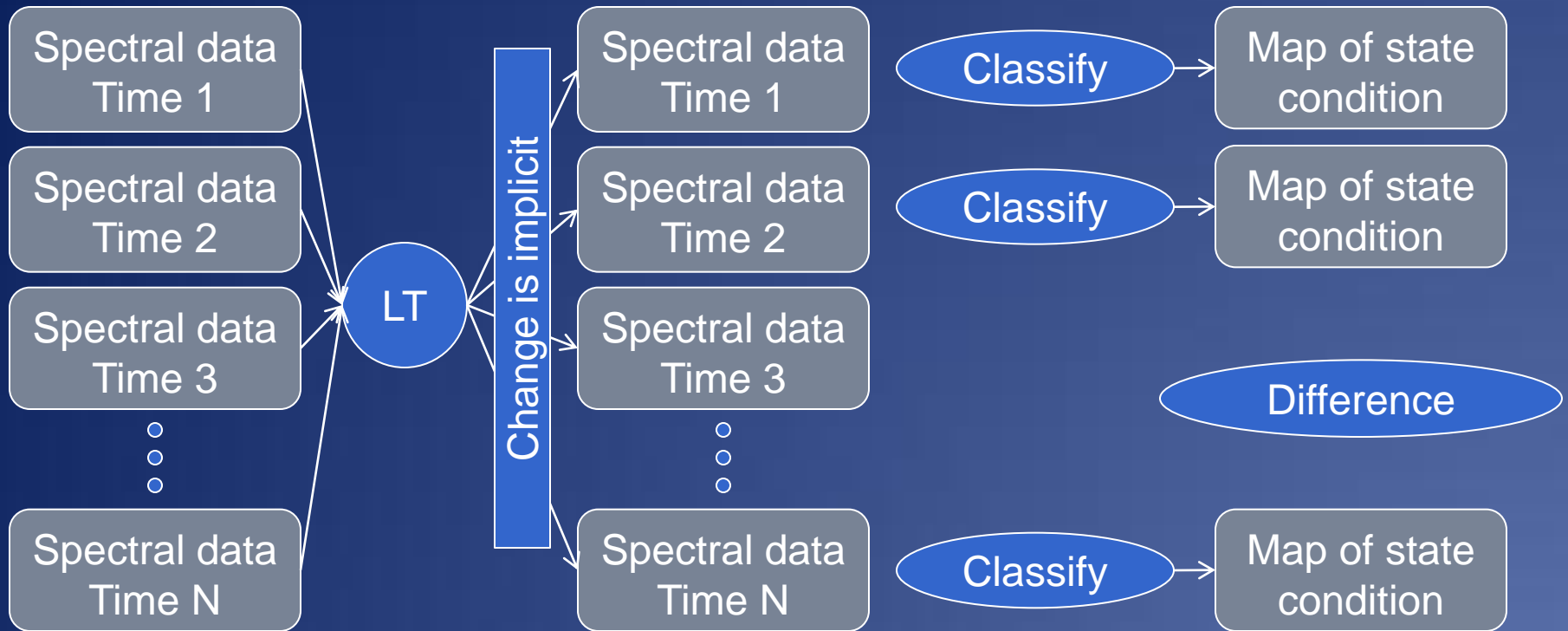|	ag to ag	ag to urban	non-ag to urban	forest to ag	phenology	class.error	class.error2
ag to ag	30	2	0	0	0	0.06	0.06
ag to urban	3	18	6	0	0	0.33	0.11
non-ag to urban	0	7	50	0	0	0.12	0
forest to ag	0	0	1	0	0	1.00	1
phenology	0	0	1	0	0	1.00	1

- Our attribution principles:
  - Identify change in process
  - Work in patches
  - Use temporal context
  - Humans train the model
- Other key pieces:
  - Random forest model is non-parametric and probabilistic
  - Process of modeling is intended to be iterative
 - Other spatial data are useful too!

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- Thanks

Temporal smoothing

- Works around a typical tension in change mapping: You can either map change or state but not both

```
Spectral data          Spectral data          Classify          Map of state
Time 1                 Time 1                                    condition

Spectral data          Spectral data          Classify          Map of state
Time 2                 Time 2                                    condition

                LT
Spectral data          Spectral data
Time 3                 Time 3                                    Difference

Spectral data          Spectral data          Classify          Map of state
Time N                 Time N                                    condition
```

Change is implicit

Maps of state condition also contain information on change

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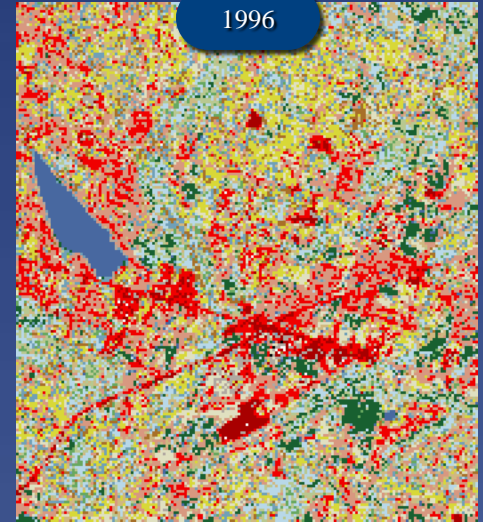# Example: Yearly NLCD-analog for Puget Sound
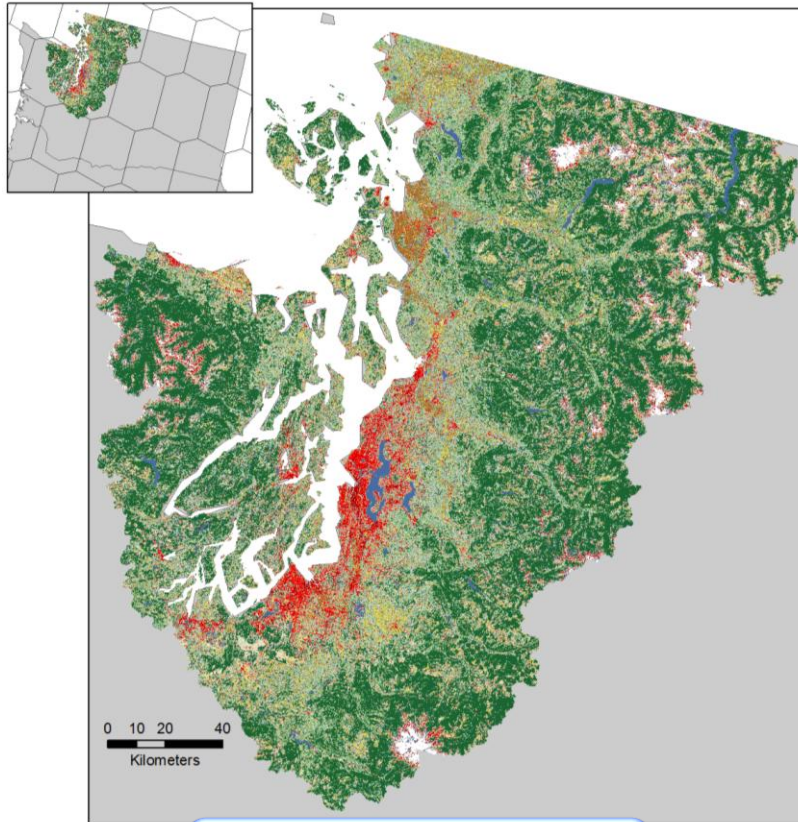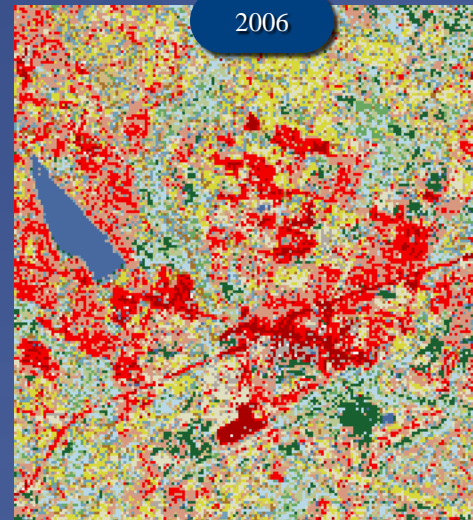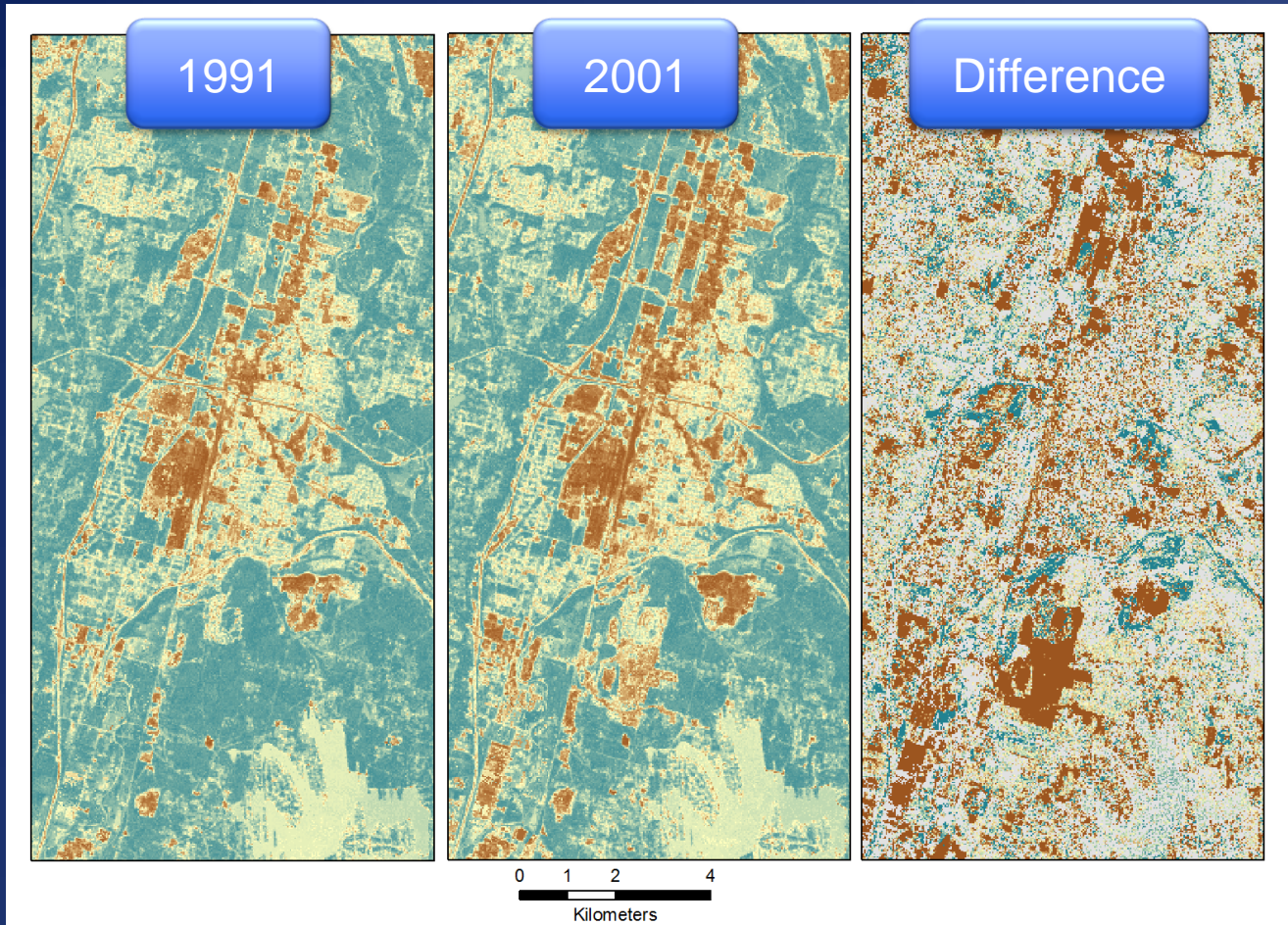

1986 NLCD[LT]
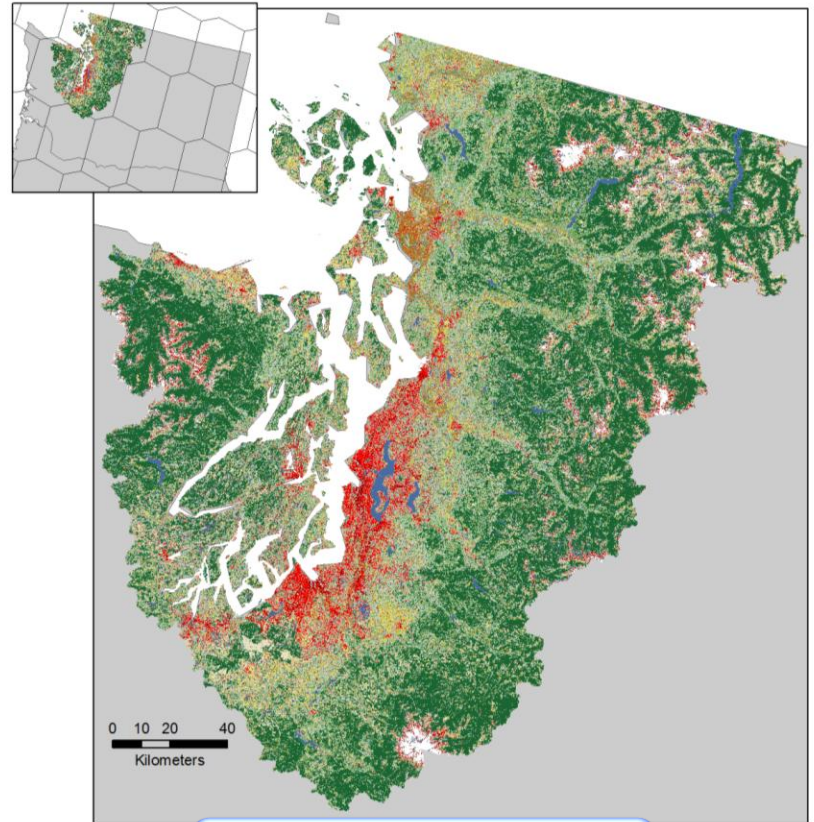
2005 NLCD[LT]

1985

1991

1996

2001

2006

Impervious cover from NLCD

1991 **2001** **Difference**

0   1   2   4
Kilometers
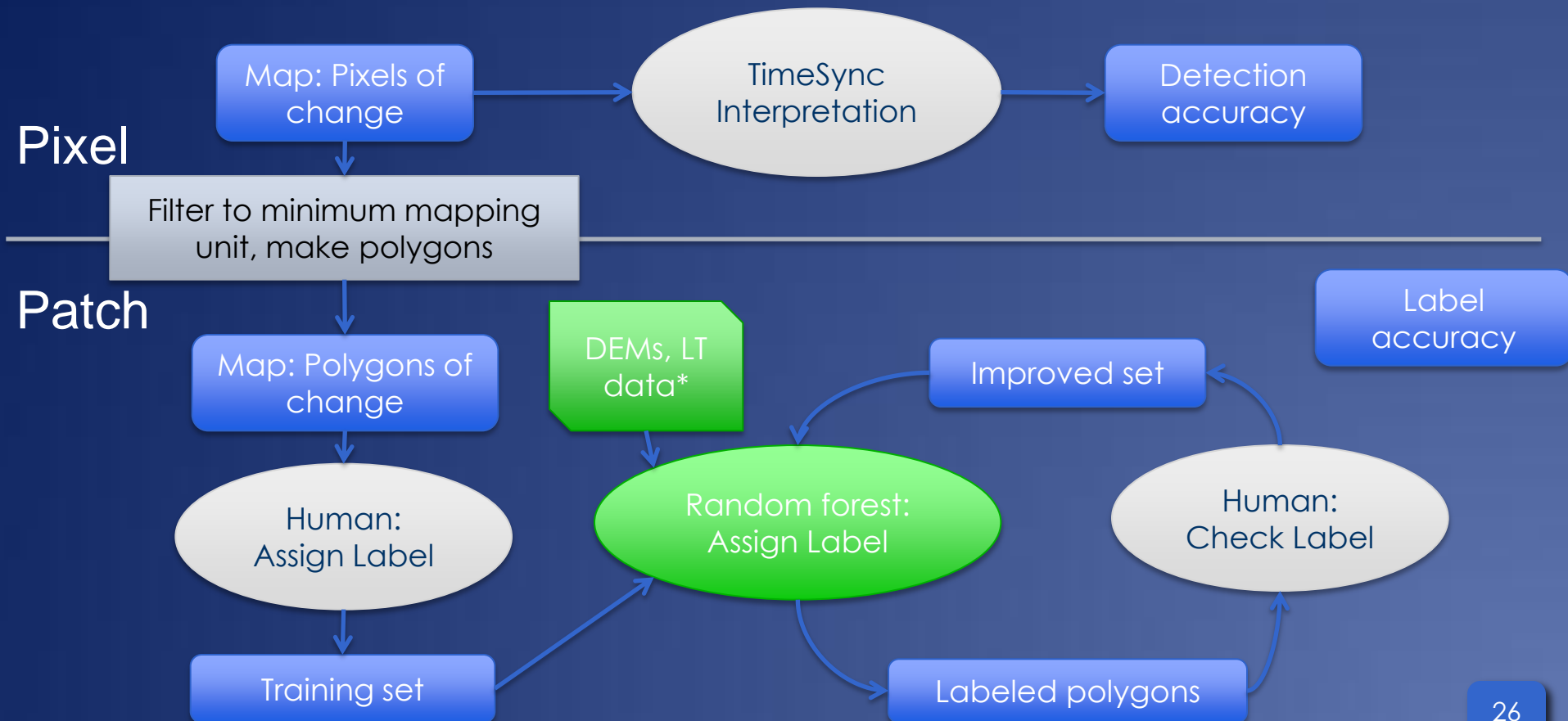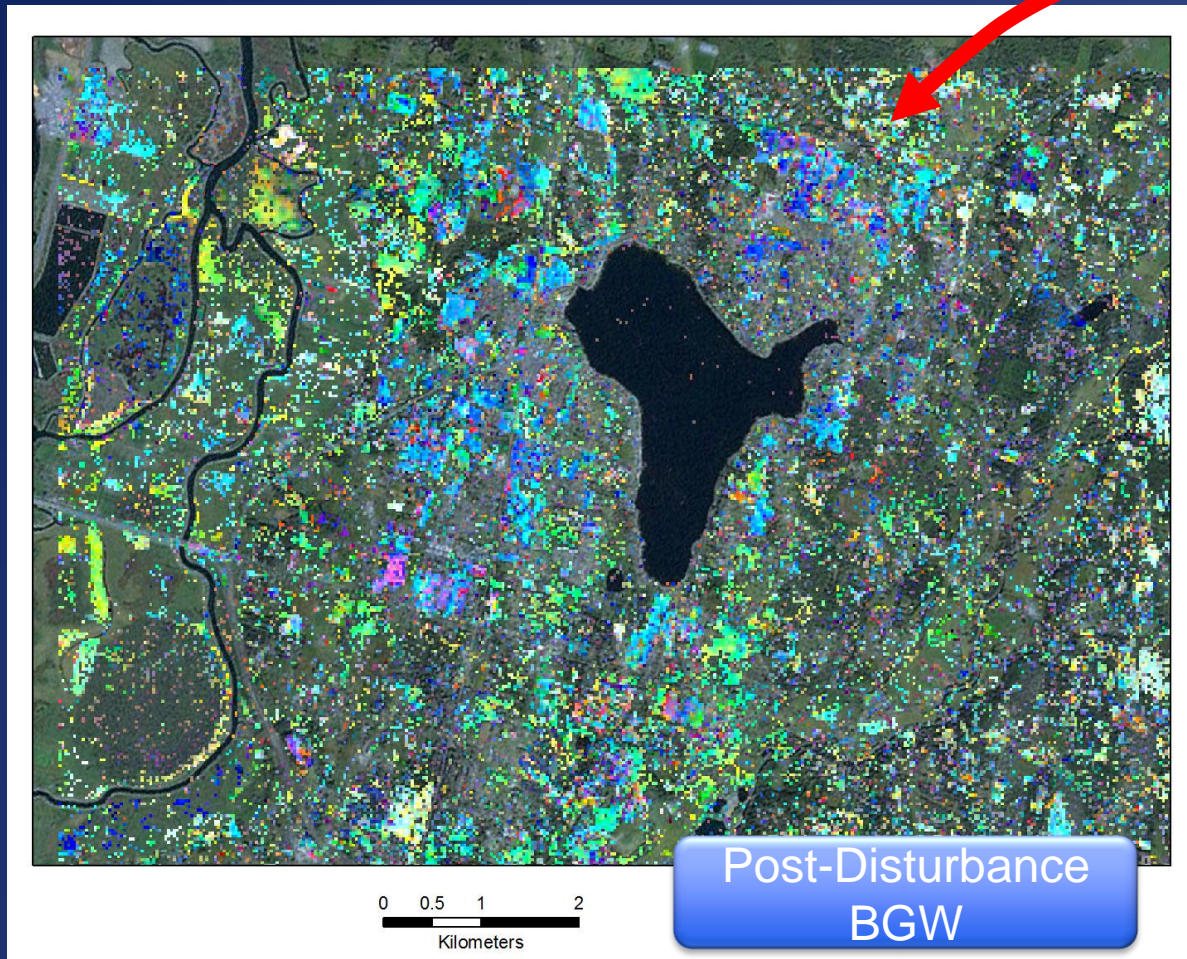
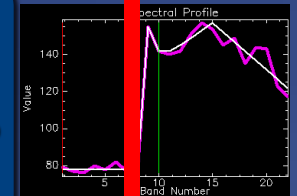Classifier based on a single year can be "painted" to other years to characterize change

Attribution and Validation

- Goal of attribution: Maximize change information and leverage human interpretation for large-area attribution modeling

Pixel

Map: Pixels of change → TimeSync Interpretation → Detection accuracy

Filter to minimum mapping unit, make polygons

Patch

Map: Polygons of change

DEMs, LT data*

Label accuracy

Improved set

Human: Assign Label

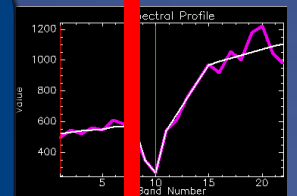Random forest: Assign Label

Human: Check Label
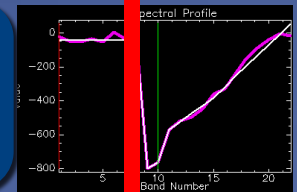
Training set

Labeled polygons

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Post-Disturbance BGW

Brightness

Greenness

Wetness

- We are no longer in the era of "luxury change"
- Temporal segmentation simplifies Landsat's spectral trajectory over years
- The simplified trajectory can be summarized into a wide range of maps
- Temporal fitting incorporates change and state information
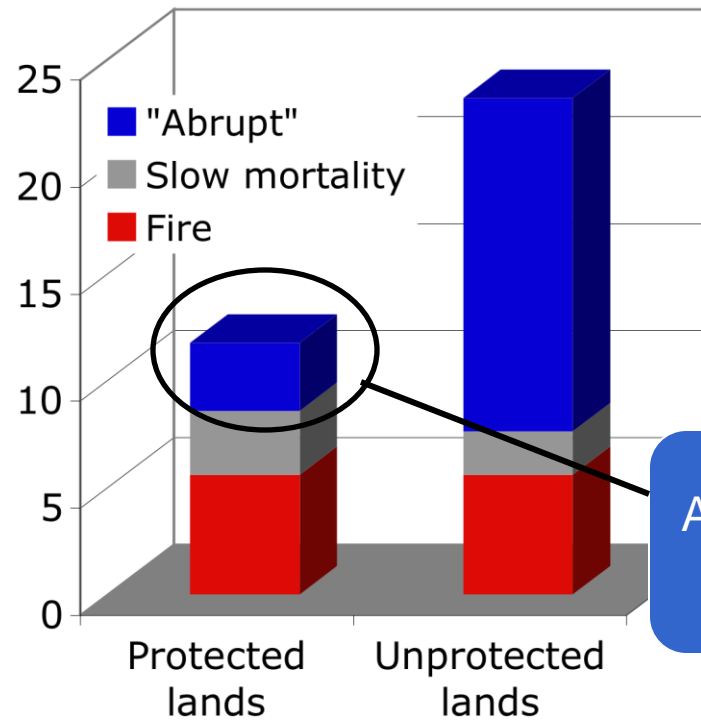- Change attribution is critical to bring inference full circle
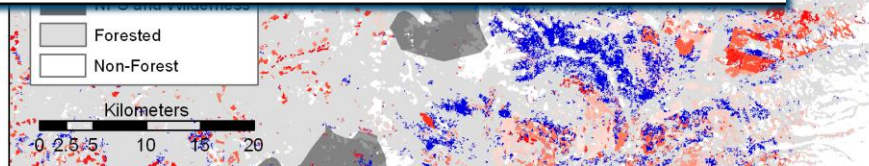
28

THANKS…

Separate by duration and known fire occurrence
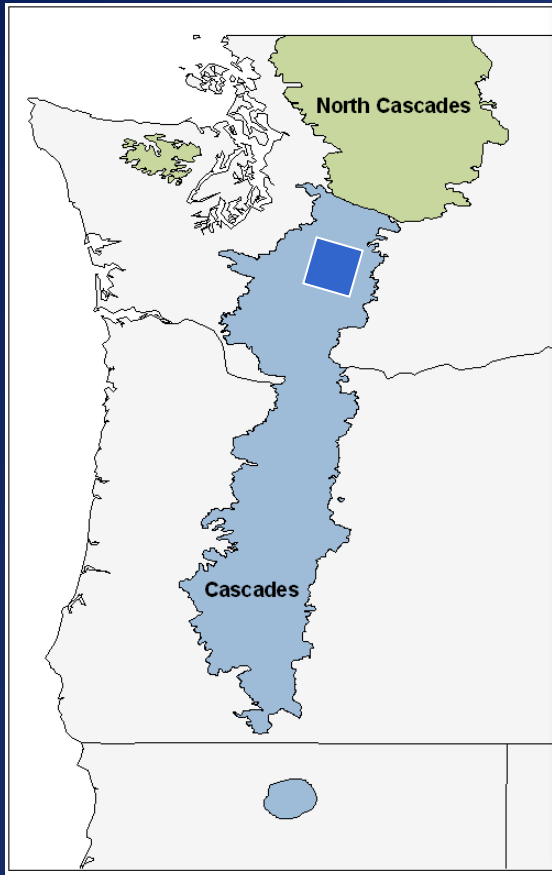
North Cascades Province: Percent Area Disturbed 1985-2008

Abrupt, but presumably natural processes

Salmonid monitoring: Full landscape change dynamic mapping

Yearly Landsat images → Temporal segmentation using single index → Vertex images

Apply to other Landsat bands

Apply rules for change-labels

Scenes

Annual fitted images

Disturbance maps

Growth maps

Post-event trajectories

Mosaicking

Spatial segmentation

NLCD cover

Annual NLCDish maps

NLCD impervious

Annual impervious maps

ESU

Integration & Labeling

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Patch size, shape

Landscape location

Pre-, post- condition

Sequence, duration of change

Archive allows better or new information

Classifier: Random Forest

Trajectory information aids

Conversion

Clearing

Fire

Wind/Water

Snow

Insect

Drought

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